

A Geospatial Approach for Fully Distributed Implementation of Mean Annual Stream Flow Regressions

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Background

Recent completion of the Elevation Derivatives for National Applications (EDNA) hydrologic derivative database has provided a modeling framework which allows for rapid implementation of regional and national scale modeling applications. A recent nation-wide application was conducted for the Department of Energy's Idaho National Engineering and Environmental Laboratory (INEEL) that allowed for a fully-distributed, geospatial implementation of estimates of mean annual stream flow for every stream segment within the United States.

EDNA is a multi-layer database comprised of derivative layers developed from the National Elevation Dataset (NED). Some of the EDNA layers include a hydrologically-conditioned elevation surface, flow direction, flow accumulation, slope, aspect, contours, synthetic drainage paths, and catchments. These layers are in a 30-meter resolution for the conterminous U.S., 60-meters for Alaska, and 10-meters for Hawaii. More information about the EDNA database is available at the EDNA home page at: edna.usgs.gov.



Development of Mean Annual Stream Flow Estimates

The underlying framework for the development of the mean annual stream flow estimates was the EDNA database, in particular, the EDNA-derived drainage paths, flow directions, and elevation. Mean annual flow estimates were developed for each of the over 1,000,000 stream segments in the EDNA database for the conterminous U.S., (CONUS) Alaska, and Hawaii using regional and state-specific regression equations. The regression equations are described below.

CONUS

Annual mean flow rates were calculated using regression equations developed specifically for each of the 18 hydrologic regions. These regression equations provide estimates for natural stream flow conditions, and require determination of drainage area, mean annual precipitation, and mean annual temperature for the upstream area. The general equation for each hydrologic region is of the form:

$$Q_m = e^a A^b P^c T^d$$

where:

Q_m	is the mean annual flow (m ³ /s)
e	is base of natural logarithms
A	is the upstream drainage area (km ²)
P	is the average annual precipitation for the upstream drainage area (mm)
T	is the average annual temperature for the upstream drainage area (1/10° F)

The exponents a,b,c, and d are region-specific coefficients derived through regression analysis.

Alaska

The regression equations used for estimation of mean annual stream flow in Alaska were developed by U.S. Geological Survey Water Resources Department (USGS/WRD) district scientists. The state was regionalized into six distinct regions for development of the regression equations which have as independent variables only upstream drainage area and mean annual precipitation. The temperature, being relatively constant throughout the state, was not found to be a significant predictor in these equations. These equations, too, are of the form:

$$Q_m = 10^a A^b P^c$$

where:

Q_m	is the mean annual flow (ft ³ /s),
A	is the upstream drainage area (mi ²), and
P	is the average annual precipitation for the upstream drainage area (mm).

Hawaii

Mean annual stream flow regression equations for Hawaii, again, were developed by USGS/WRD district scientists. Separate regressions were developed for the windward and leeward sides of the islands. Significant variables for the windward areas were drainage area, mean annual precipitation, and the precipitation intensity of the 24-hour/2-year storm. The equations for the leeward areas had the same independent variables, but also included the mean elevation and the elevation range for the basin. The equations are of the form:

Windward Sides: $Q_m = 0.015^*(A^{.949})^*(P^{0.588})^*(PI^{1.850})$
Leeward Sides: $Q_m = 0.0000000693^*(A^{.746})^*(E^{1.657})^*(R^{0.154})^*(P^{2.783})^*(PI^{-1.588})$
where:

Q_m	is the mean annual flow (ft ³ /s)
A	is the upstream drainage area (mi ²)
P	is the average annual precipitation for the upstream drainage area (mm)
PI	is the precipitation intensity, 24-hour rainfall (inches) having a recurrence interval of 2 years
E	is the mean basin elevation (ft)
R	is the basin range (ft)



Data

The data necessary for elevation of the regression equations were derived from various sources.

Area

The drainage area, required for the CONUS, Alaskan and Hawaiian regressions, was easily derived from the EDNA database. The flow accumulation layer provides the upstream area above each pixel. A simple conversion from pixel count to area was applied.

Elevation

Both the mean elevation and the range in elevations, required inputs to the Hawaiian regression equations, were derived directly from the EDNA Digital Elevation Model (DEM).

Mean Annual Precipitation

Mean annual precipitation values in millimeters for the CONUS and Hawaii were taken from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Spatial Climate Layers for the United States. For the drainages originating in Canada and Mexico, average annual precipitation (in mm) was taken from Global Temperature and Precipitation Climatologies. Both data layers were re-projected from the original geographic framework into the USA Contiguous Albers Equal Area Conic geographic projection. The PRISM data, while available for Alaska, where not used due to the vintage of the regression equations. In order to produce a precipitation map that would be of a comparable vintage to the regression equations, a mean annual precipitation layer was created using contours as represented in the 1978 Environmental Atlas of Alaska.

Mean Annual Temperature

This variable was needed only for evaluation of the regression equations for the CONUS. In a fashion similar to that used to assemble a mean annual precipitation dataset for the CONUS, this variable was obtained through use of the PRISM data within the CONUS and the Global Temperature and Precipitation Climatologies for the drainages outside of the U.S.

Precipitation intensity

Precipitation intensity of the 24-hour storm with a return period of 2 years was a required input to the Hawaiian regression equations. These data were derived from isopluvial maps available in the Rainfall-Frequency Atlas of the Hawaiian Islands. Conversion to a raster layer was achieved by using the Inverse Distance Weighting technique.

Evaluation of Regression Equations

In order to efficiently evaluate the mean annual flow for all 1,000,000 stream segments within the EDNA database, advantage was made of the continuous parameterization technique to aggregate several areal-dependent variables. In essence, this methodology makes use of the EDNA flow direction matrix to integrate a spatial variable over the topographic surface.

The standard methodology for evaluating the mean basin characteristic has been to (1) delineate the watershed above the basin outlet and (2) do an overlay procedure to develop the mean characteristic within the watershed. Considering the size of our problem (estimation of streamflows for 1,000,000 stream segments), this approach was not feasible. The continuous parameterization technique allowed for rapid characterization of all the necessary spatial parameters.

For example, to evaluate the total precipitation falling within a given watershed drained by a stream segment, we need to integrate the spatially variable precipitation over the watershed area. This can be written: $P = \int_a p(x,y)da$ where:

P	is the total precipitation falling on the watershed (in units of depth)
$p(x,y)$	is the spatially variable precipitation (in units of depth)
a	is the watershed area (in units of area)

Once the surfaces defining the independent variables are developed using the continuous parameterization techniques, attribution of each stream segment with the appropriate watershed characteristic was done using raster sampling and evaluation of the regression equations was a simple algebraic operation carried out within a database environment.

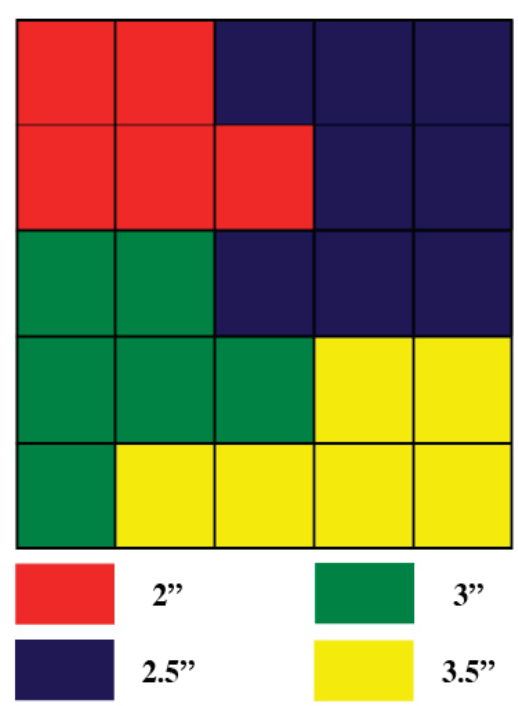
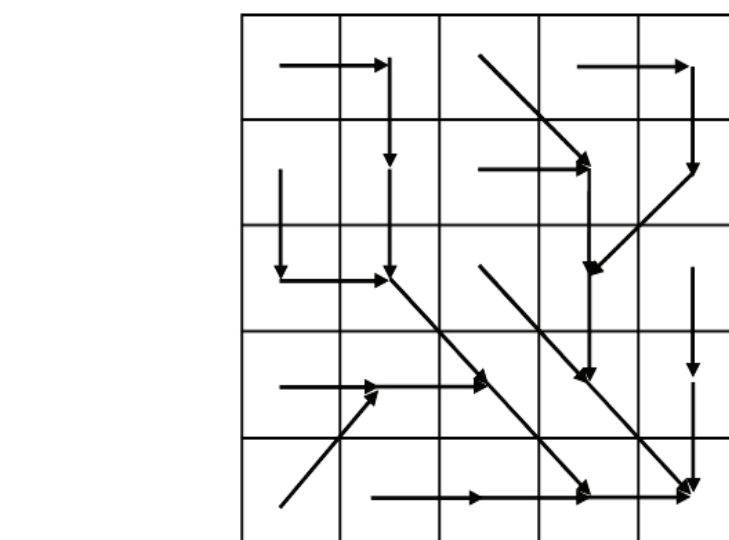


Figure c. Precipitation grid for small area with values from 2 to 3.5 inches.

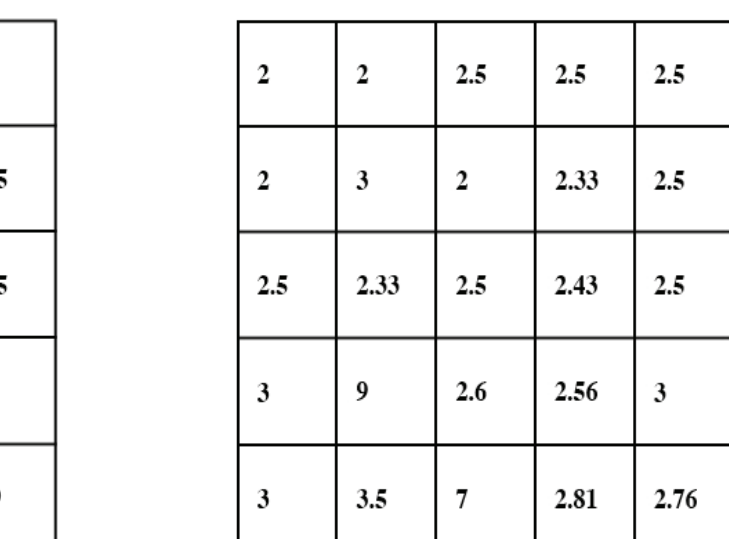
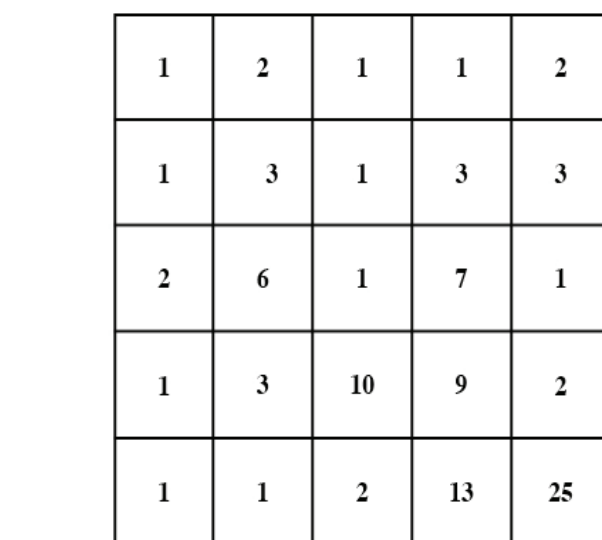
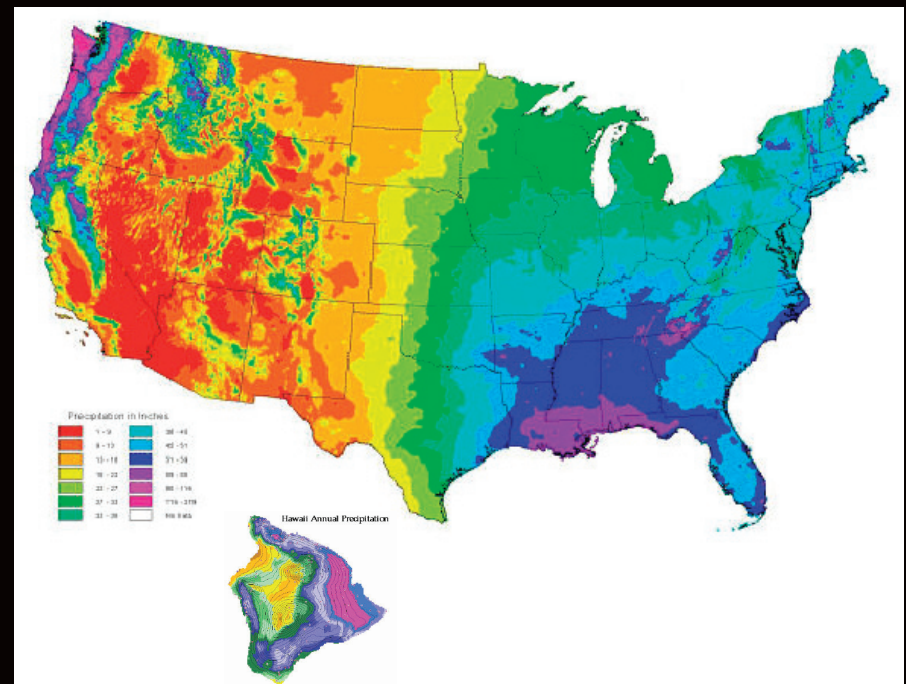


Figure e. The average precipitation for the drainage area above each cell in inches.



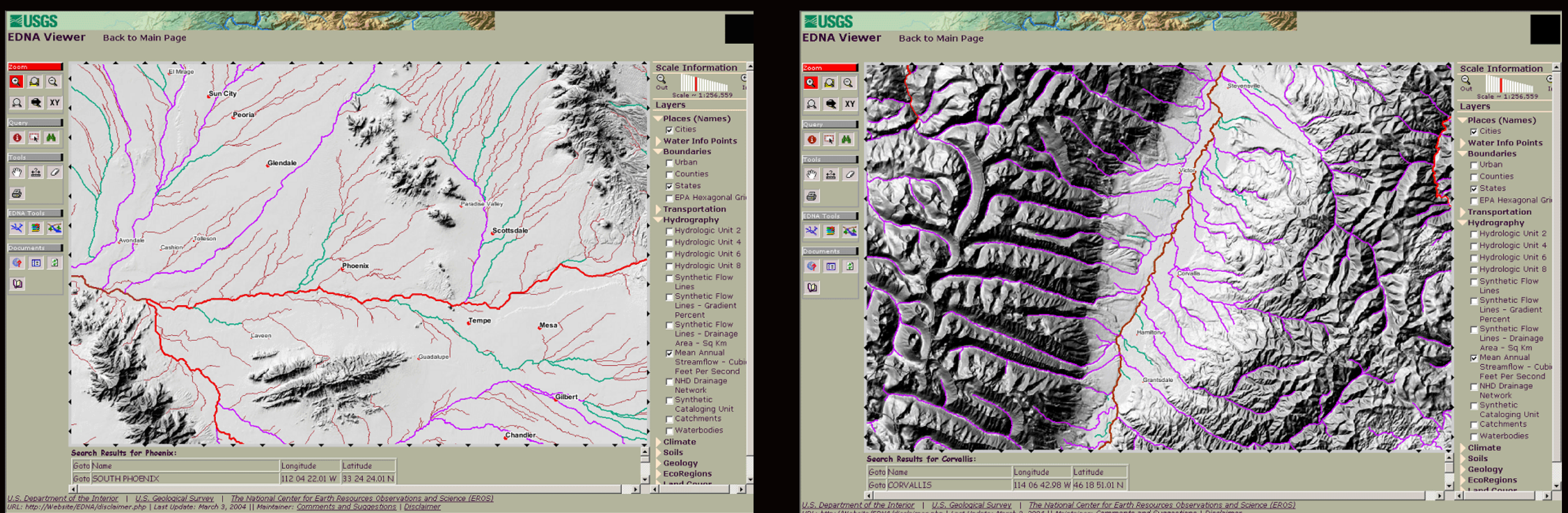
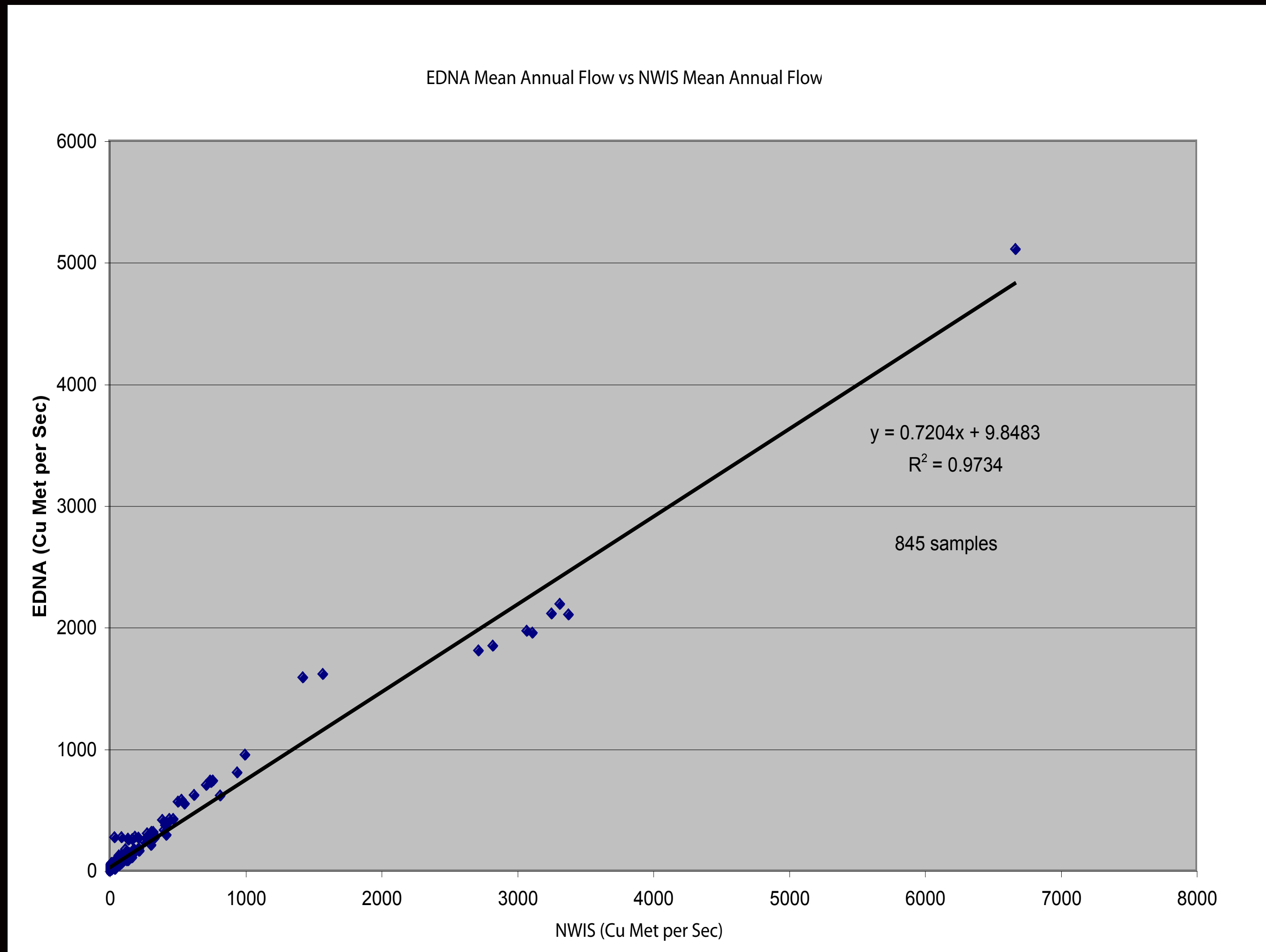
Mean Annual Precipitation for the United States

Results

The evaluation of the three sets of regressions equations resulted in estimates of mean annual flow for over 1,000,000 stream segments within the EDNA database. Comparison of the estimates of mean annual stream flow as generated using the regression equations with those from long-term stream gage records was made to evaluate the accuracy of the analysis. In order to facilitate this comparison, the NWIS database was used. The database was filtered to remove gages in the HCDN network and to extract only those gages with a minimum of 10 years of record. The HCDN gages were removed because these gages were used in the development of the regional regression equations for the CONUS. The remaining NWIS gages were then located on an appropriate EDNA drainage path, thereby enabling comparison between the EDNA-based regression estimates of streamflow and the mean annual flow as calculated directly from the NWIS record.

Shown here is a plot of the EDNA-based regression estimates vs. the mean annual flow derived from the NWIS database for 845 gages within Hydrologic Region 17 (the Pacific Northwest). The data correlate quite well, with an R² of over 97%. The remaining regions will be evaluated as well. Examination of the NWIS record to flag gages with significant regulation of flow and streamflow trends is on-going as well.

The results of the streamflow estimation work has been implemented through a web-interface by both the USGS and INEEL. INEEL has just release their Virtual Hydropower Prospector (VHP) which displays the power potential of every stream in the country, and shows prime locations for development. The EDNA site has several web-enhanced tools for “on-the-fly” basin characterizations. Additional browse capabilities allow users to display streams using various color schemes.



EDNA Stream lines color coded by mean annual streamflow. Phoenix, a dry region, shows fewer large streams than the Corvallis area.